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ISS Acoustics Mission Support

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ABSTRACT

The ISS Acoustics Office provides space flight mission support on all acoustic-related issues and tasks. As part of this support, we define, develop, and implement requirements for a comprehensive noise mitigation program for space flight and the International Space Station. To ensure these requirements are complied with, we utilize on-orbit testing to define the environment, derive measures to safeguard the health, safety, and well being of flight crewmembers, and work on measures to reduce unacceptable levels. This program preserves crewmembers' hearing and provides for a safe, productive, and comfortable noise environment. This paper describes crew training with acoustic measurement devices, on-orbit testing, real-time remedial actions, the types of data produced, and examples of recommendations that are made to protect the crewmember's hearing.

1. INTRODUCTION

An area of interest aboard the International Space Station (ISS) is the acoustic environment. The life support systems and experiments incorporate variable speed fans, pumps, and motors that create noise. Most of these systems and experiments operate 24 hours a day. The establishment of a safe, productive environment on the ISS is critical to the success of the ISS mission. Careful monitoring of all aspects of the environment, including the acoustic noise levels, will help assure that the crew lives and works in the best possible environment. The use of crew interactive acoustic monitoring equipment is the primary method for assessing the noise levels onboard the ISS.

The ISS Acoustics Office provides space flight mission support on all acoustic-related issues and tasks. As part of this support, the office defines, develops, and implements acoustic requirements for a comprehensive noise mitigation program for space flight and the International Space Station. The ISS program develops measures to safeguard the crewmembers' hearing, ensures there are work-arounds for excessively noisy areas or mission events, and provides for a secure, productive, and comfortable noise environment. This is aided by module noise monitoring, noise abatement, and restricting crew noise exposure during a mission.

2. TRAINING

Acoustic mission support involves an interaction with the crew from training to mission debriefing. From space programs such as the Shuttle and MIR to the International Space Station, acoustics data has been taken with both dosimeters and sound level meters. The Acoustics Office writes procedures for the hardware that crewmembers train on. The procedures go through a validation process where a crew-office representative (usually a future astronaut) reviews the procedures step-by-step and offers suggestions on how to clean up or clarify certain steps.

Training is scheduled through the Increment Training Integrator (ITI) who tells the Crew Activities Officer (CAM) when and what lessons the crew needs according to the crew training catalog. Currently, crewmembers train in both the United States and Russia. The Environmental Health System (EHS) acoustic lesson is scheduled to occur while they're in the United States. The acoustic training sessions usually start with the audio dosimeter for its ease of operation. The Audio Dosimeter is used to measure noise exposure over extended periods of time. The procedures teach the crewmembers how to power cycle (turn off and back on) the dosimeter, navigate through the various modes, and document the data at the end of a 24-hour or other length measurement period.

The instruments currently used on orbit are Ametek® Mark I Audio Dosimeters. An extension cable is included that allows the microphone to be clipped to the crewmember's collar. In nominal mode, the dosimeter meets the specification requirements of ANSI S1.25-1978. In sound level meter mode, the instrument conforms to the type S2A accuracy requirements in ANSI S1.4-1983, and IEC 60651. Off-the-shelf equipment, such as the dosimeter, requires modification to meet flight requirements. The dosimeter has a number of modifications: the casing is coated in silver aluminum tape, Velcro is added for on-orbit attachment, a high temperature decal is added in the event the device overheats (temperature sensitive label), the circuit boards are coated to preclude moisture/electrical shortage, and the microphone extension cable is wrapped in Nomex cloth. These modifications either facilitate operations, make the instrument safer, more reliable to use, or reduce the susceptibility of the instrument catching on fire (see Figure 1). The dosimeter also undergoes the standard battery of tests such as: Off-gassing (dosimeter elevated in a vacuum so that the volatiles come off quickly); EMI (electromagnetic radiation measurement during operation); and 72 hr. continuous ambient burn-in (to screen for early hardware problems).

The second part of the training is on the sound level meter, which is used to take measurements of the continuous ambient noise in the modules. Whereas the dosimeter is used for long-term exposure, the sound meter is used to take a "snapshot" of the sound at various locations in the space station. The procedures teach the crewmembers how to set-up the meter, record the data, and save the data. The Sound Level Meter (SLM) used is a Bruel and Kjaer (B&K) 2260 Investigator™. The B&K 2260 is a hand-held, battery-operated, two-channel sound analyzer comprised of hardware and embedded operating-system software. It is used for high-quality, real-time sound analysis over an averaging time of 15 to 30 seconds in this application. Basic sound analysis software converts the instrument into a precision sound level analyzer that conforms to IEC 61672-1 and Type 1 accuracy requirements in ANSI S1.43-1997. Several types of sound meters were used in the shuttle program, but it wasn't until the space station that this new instrument was used. In support of flight, the sound level meter undergoes two modifications to the battery compartment: pigmat, an absorbent material, is added in case of battery leakage, and a Teletemp (temperature sensitive label) is added in case of a short in the battery circuit. Figure 2 shows Russian cosmonauts, M. Turin and V. Dezhurov, being trained on the sound level meter.

The last part of the training teaches the crewmember how to download the sound level meter data through direct interfacing with the Medical Equipment Computer (MEC) using software developed by B&K called Noise Explorer™. The MEC contains all of the software used by the crewmembers for their medical testing.

After the training is complete, crewmembers may request refresher training on any of the hardware, even during the 7-day quarantine period prior to launch.

3. MISSION SUPPORT

During the on-orbit acoustic measurements, a representative from the Acoustics Office supports Mission Control in Houston to assist the crew, should they have any problems when using the hardware. Since acoustics falls under Biomedical, the acoustics representative sits in the Biomedical engineering Multi-purpose Support Room (MPSR) during the scheduled measurement sessions. From there, the representative can talk to the flight directors, the flight surgeons, and even directly to the crewmembers through an internal system called the Digital Voice Intercom System (DVIS) over a space-to-ground loop.

During the first 5 Expeditions, dosimeter measurements were scheduled for twice per Increment. The dosimeters can either be worn by the crew or hung in a static location to determine noise exposure, equivalent sound pressure level, in dBA. The measurement period is currently 24-hours, and the sessions are split into a 16-hour workday and an 8-hour sleep period. These values are then combined mathematically into an equivalent 24-hour exposure level. The dosimeter also records other levels such as Lmax, or the loudest level the dosimeter was exposed to during the recording. To ensure accuracy of the data, all dosimeters are sent to the vendor for calibration each year. Twelve dosimeters are rotated to ease re-supply (sent back and forth to the ISS) since they must be ready leave the ground at launch minus 7 months. There is no mechanism in place to calibrate the dosimeters once they're on-orbit.

As an example of the need for mission support, it was decided real-time during Expedition 3 to change the internal jumper settings in the dosimeter. These settings are used to set the operating range, the threshold level, the exchange rate, etc. In this case, a different operating range was preferred for a particular measurement location. Procedures were written for the crewmembers to help them remove the back cover, properly configure the switches, and retest the dosimeters. Three good measurements were recorded shortly afterwards.

For the sound level meter, measurements were scheduled for once per month during the first four Increments. Since then, the schedule has been cut back to twice per Increment due to the consistency of the data. Before readings are taken, agreements on location and timing of measurements between all pertinent international partners and module owners must be in place. These agreements and predefined measurement plans are found in internal NASA documentation such as the Increment Definition Requirements Document (IDRD) and the On-Orbit Schedule (OOS). The first time the meter is destowed, it is put through a series of "checks" to ensure that all of the settings have remained the same from the time it left the ground. Once this "SLM Checkout" is performed, the instrument can be used to take measurements.

In preparation for taking on-orbit measurements, a set of instructions is sent up to the crew the day of the measurements. These instructions are in addition to the on-board acoustic measurement procedures and include the list of measurement locations and any additional instructions needed for clarification of that day's activity. The measurements are taken throughout all modules currently attached to the Space Station. As an example, in the U.S. Laboratory, measurements are taken 8 different locations corresponding to rack bays down the length of the entire module. These measurement points are held consistent for comparison to previous measurement sessions. In actual performance of measurements, the meter is held at 70 degrees from horizontal while no other intermittent noises, such as voice, are present. In Figure 3, Cosmonaut S. Krikalev is shown taking sound level meter measurements onboard the ISS in one of the Russian segments called the Service Module (SM).

To ensure the accuracy of the data, the sound level meters are fully tested and calibrated annually. Before launch minus seven months, each sound level meter is sent to the vendor and calibrated according to the requirements of ANSI/NCSL Z540, ISO/IEC 17025 as well as the guidelines of ISO 10012-1. During this calibration, the frequency response and the sensitivity is measured and compared with the appropriate specifications. In order to facilitate the manifest schedule, four different SLMs are rotated through pre-flight processing, launch, in-flight use, return, post-flight processing and factory calibration. In addition to the yearly calibration, an on-orbit internal calibration is performed before each measurement. To make sure the sensitivity has not changed, this internal calibration method uses charge injection to measure the capacitance of the microphone cartridge.

Upon completion of the measurements, the SLM is connected to the MEC through an RS-232 cable for downloading the data. The interactive Windows program, Noise Explorer (see Figure 4), steps the crewmember through checking that the SLM is connected properly, selecting the appropriate files for transfer, and saving the project. The data is then retrieved from the on-orbit software support group. They scan the onboard computers for the files and transfer them during available communication sessions. The data is then dispersed to the Acoustics Office, their Russian counterparts, and other JSC organizations through secure email.

Real-time mission support occurred as early as Increment 1 for the sound meter. The instrument was not recording the expected sound data. The levels were around 20 dB instead of 55-75 dB. The crewmembers held up a piece of paper to the video camera and drew a diagram of the sound meter, illustrating an arrow to the very tip of where the protective grid was supposed to be. From the live video feed, it was evident that the crew could not see a protective grid on the microphone because it had become unscrewed. After further inspection, the crew also determined that the diaphragm had been accidentally punctured. It was unprotected during shipment to the space station.

In Increment 3, during a depressurization pump checkout in the Airlock (the module used for Extravehicular Activity (EVA)), the crew in the Node (the module currently used to connect the Functional Cargo Block, Airlock, and U.S. Laboratory) reported loud, high-pitched noise (>100 dB) coming from the vestibule area. The vestibule is the hatch between the Node and the Airlock. Later troubleshooting indicated that the depress pump return hose was the source of the noise. The crew also reported that the depress return hose behind the closeout was too long for the area in which it was installed (approximately 5 feet in length). The depress return hose connection at the Node was removed for EVA operations and the problem was eliminated. The ISS Commander reconnected the hose briefly during some depressurization activities and the sound returned. Boeing, Huntsville, put together a failure investigation team with the help of Sam Denham, Boeing acoustical engineer. They simulated the system, recreated the noise, and found a solution. The problem was fixed on Increment 4 by shortening the return hose to an appropriate length.

4. DATA ANALYSIS

After receiving the data from the sound level meter, the acoustic office converts the Noise Explorer files to Excel files for analysis. The data from the dosimeter appears in an Excel spreadsheet (see Figure 5). As part of the analysis, the data is compared with previous data and checked against the station hardware health and operational status reports that are released on a daily basis. These reports detail which systems are active and which are not. As an example, in some of the recent data, it became apparent that one of the Common Cabin Air Assemblies (CCAAs), or air conditioners, in the U.S. Laboratory has been consistently louder than the other. In Figure 6, the two upper curves represent the noise signature of the port side CCAA. The two bottom curves represent the starboard side CCAA. One of each was recorded in the last two Increments. From 125 Hz to 2000 Hz, the port side CCAA is considerably louder. This becomes important when the usage numbers are taken into consideration. The total noise level in the modules must meet continuous noise limits specified in program requirements documents. These types of observations are summarized in preliminary reports to the crew surgeons, crew representatives, and members of the Acoustic Working Group.

One of the medical flight rules sets noise exposure limits based on a 24-hour exposure level. If the 24-hour noise exposure levels (L_{EQ24}) measured by the audio dosimeters exceeds 65 dBA, then the crewmembers are directed to wear approved hearing protection devices. Design specifications of 60 dBA for work areas and 50 dBA for sleep areas have been agreed upon as “safety limits” for ISS operations. The ISS specifications take into account the impact of noise on crew hearing (both temporary and permanent threshold shifts), as well as habitability and performance (disrupted communication, irritability, impaired sleep, etc.).

In the preliminary data report developed by the acoustics office, recommendations on how to protect the crew’s hearing are made. These recommendations may be in the form of hearing protection requirements, requests to deactivate certain systems, or limits to noise exposure in certain areas of the ISS. Based on the flight rule above, the use of hearing protection devices (HPDs) is suggested if noise exposure levels exceed 60 dBA, or if the crewmembers are exposed to high intermittent noise periods (e.g. use of exercise devices such as the treadmill, airlock repress, or other short term high noises). Use of HPDs during sleep provides additional lowering of the noise input to the inner ear and aids recovery from acoustic trauma sustained during the day. Recovery is more robust in quieter environments such as in an adequately quieted crew sleep station or with the use of hearing protection during high noise exposure periods.

At the end of an Increment, an ISS Acoustic Environment Increment Report is generated that presents all acoustic measurements. This report contains the analysis and recommendations that occurred during that Increment. Increments typically last around four or five months.

5. SUMMARY

The acoustic environment on board the International Space Station has become one of the highest crew habitability concerns. The acoustics mission support function, including training, mission control support, and data analysis, is necessary to monitor crew exposure and ensure that the crewmembers’ hearing is not at risk. Without accurate on-orbit data, all preventative ground efforts are rendered ineffective. Mission monitoring and support is critical to the control and mitigation of acoustic noise on the International Space Station.

6. ACKNOWLEDGEMENTS

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APPENDIX

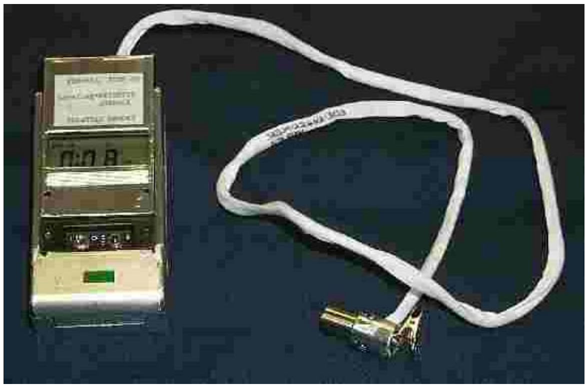

Figure 1: ISS Audio Dosimeter

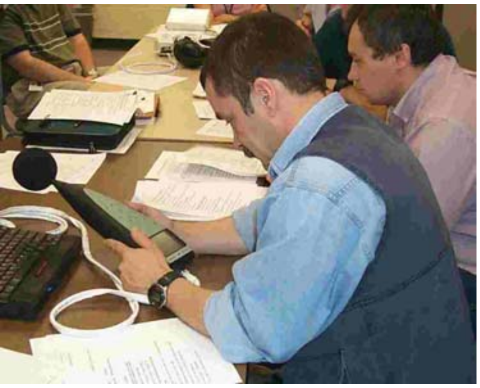

Figure 2: Russian cosmonauts, M. Turin and V. Dezhurov, being trained on the sound level meter.

Figure 3: Cosmonaut S. Krikalev taking sound level meter measurements onboard the ISS

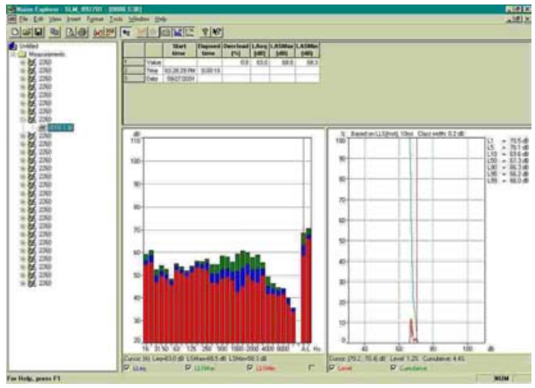

Figure 4: Noise Explorer screen shot

Test Data Log

Flight #: __________
Crew Member: __________
Date: __________

			Recorded Parameters				
Dosimeter Serial No.	Crew Member or Static Location	Activation Time (GMT)	DOSE %	Lavg/Leg dBA	SLM dBA	Lmax dBA	TIME hours:min.

Crew Comments:

Figure 5: Dosimeter data log screen shot

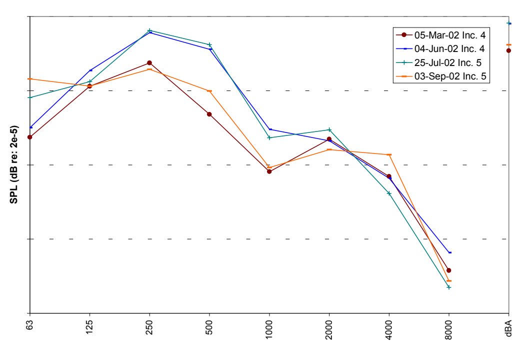

Figure 6: CCAA Comparison